2026 RPPR Interim Progress Report

Agreement Number: N000142312053

Principal Investigator:

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Award Period of performance beginning: 01/01/2023 and ending: 12/31/2027

Title: DRI The Arabian Sea Transition Layer (ASTraL) Exchange across the Air-Sea Interface

Submitter Email: fernando.10@nd.edu **Submitted By:** Dr. Harindra J. Fernando

Distribution Statement:

A - Approved for public release; distribution is unlimited.

Major Goals:

Every year, during March to May, a compact region of elevated Sea Surface Temperature (SST > 30 degrees C) develops in the Southeastern Arabian Sea (SEAS). This phenomenon is believed to have strong implications on biophysical interactions and underwater acoustics in the Arabian Sea (AS) as well as initiation of boreal summer Southwest (SW) monsoons. Known as the Mini Warm Pool (MWP) because of its smaller size compared to other warm pools in the world, MWP develops over an area with solar insolation comparable to the rest of the AS, suggesting that a myriad of interacting multiscale atmospheric and oceanic processes independent of solar insolation distribution is responsible for MWP. This project was originally intended for research on dynamical process underpinning the lifecycle (genesis, maturation, and dissolution) of MWP by participating in the ONR-ASTraL (Arabian Sea Transition Layer) Departmental Research Initiative. The origins of MWP can be traced to the collapse of summer SW monsoons of the yesteryear, during which oceanic coastal planetary [Kelvin] waves are generated in the Bay of Bengal (BOB). These waves together with low saline water arriving in SEAS during the winter Northeast monsoon produce a large anticyclonic eddy in SEAS, signifying a downwelling Rossby wave. This feature, known as the Lakshadweep high (LH), is the hub of MWP.

Accompanying and evolving physical processes underlying MWP are numerous: the formation of a thicker and warmer barrier layer topped by a thin low-salinity colder surface layer separated by a pycnocline; air-sea interactions regulated by boundary layers on either side of the ocean surface [together known as the transition layer]; the presence of a low-level westerly jet and associated instabilities; and development of deep convection in SEAS that leads to the Monsoon Onset Vortex.

Four guiding hypotheses were proposed to undergird data analysis. They concern: (i) development of MWP during the evolution of air-sea fluxes in the transition layer due to evolving large-scale environmental forcing and micro-scale response thereof; (ii) warming of the thin upper mixed layer of LH via entrainment at the pycnocline, temperature inversions and lateral processes; (iii) generation of SW monsoon onset vortex as a result of instabilities of the low-level westerly jet, and amplification of the resulting cyclonic vortex via enhanced turbulence and fluxes ensuing from deep convection and breakdown of instabilities; and (iv) rapid dissolution of MWP with the SW monsoon onset due to a combination of intense upper ocean turbulence, development of mesoscale structures and propagating planetary waves (e.g., westward migration of LH).

These four hypotheses are to be tested, and relevant research questions addressed by participation in all three completed ASTraL field campaigns in 2023, 2024 and 2025, wherein an extensive suite of atmospheric and oceanic instruments are deployed by University of Notre Dame (UND) group. Meso- and micro-scale processes active in MWP were to be investigated using a novel large eddy simulation (LES) approach by a co-PI from National Center for Atmospheric Research (NCAR).

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During the first EKAMSAT/ASTraL pilot cruise in 2023 (11–24 June), preliminary observations were made in the Eastern AS, but due to geopolitical constraints the 2024 (Leg 1: 18 May–13 June, Leg 2: 18 May – 13 June) and 2025 (Leg 1: 3-15 May 2025, Leg 2: 19 May – 16 June) cruises were relocated to the Bay of Bengal (BOB). This required revision of science plans, with revised plans focused on BOB processes that perceived to be akin to those in SEAS-MWP. These included: (i) the evolution of convectively coupled Kelvin waves across AS and Indian Ocean (IO), emanating from east African Highlands and propagating eastward; (ii) the role of capping inversion in modulating the convection development, and associated feedbacks relating clouds, solar insolation, SST, and air-sea fluxes; (iv) low-level jets in SEAS and their extension to BOB, (iii) cold pool formation during precipitation events and their influence on air-sea interactions; (iv) investigations of [monsoon] depressions, their evolution, propagation of associated airmasses, precipitation distribution, and their possible role in monsoon onset and propagation.

NCAR's computational research in collaboration with observational work by UND focused on air-sea interactions studies using LES, in particular, the impact of ocean heterogeneity on marine atmospheric and oceanic boundary layer (MABL, OBL) dynamics. Ocean heterogeneity specifically refers to horizontal gradients in SST and currents, which arise naturally due to an abundance of mesoscale and submesoscale ocean fronts and eddies. Process studies and phenomenological discoveries are at the heart of the computational component. Simulation results are complementary to observations, and they are to be used as guidance for collecting and interpreting field data. For ASTral, NCAR will pose process studies in both ABL and OBL. In addition, they are undertaking a large-eddy simulation study of the high-wind ABL imposing a spectrum of measured waves as surface boundary conditions. The wave spectra are obtained in the ONR MURI Study on Air-Sea Coupling with WAves, Turbulence, and Clouds at High winds (SASCWATCH). A tropical cyclone passed near the ASTral observations collected in FY24 with winds approaching 15 m/s.

UND-NCAR program was designed to be synergistic, in that intercomparison of field and numerical outcomes is expected to cross fertilize individual programs. In addition, close collaboration is to be maintained with scientists of southeast Asian nations (India, Sri Lanka, Maldives), Naval Research Laboratories NRL (Monterey and Stennis) and other ASTraL PIs, building upon existing partnerships. Close collaboration is maintained with NRL Groups on instrument deployment, shipments, personnel exchange between institutions, data analysis and publications, which is evident from the dissemination record. Training of STEM students, post-doctoral fellows, early career scientists and technical staff are an integral part of the project. The results are to be published in archival journals, and circulated to a wider audience via presentations in national and international conferences.

Further information is provided in the project webpage:
https://efmlab.nd.edu/research/astral/

Accomplishments:

Analysis of 2024 cruise observations during the pre-monsoon season showed a strong low level capping inversion over the Northern BOB (NB) and a weaker yet noticeable inversion over the Central BOB (CB) aloft MABL, with a highly stably stratified free troposphere (Figs. 1a and 2a; see attached pdf). The inversion at the NB occurred at ~ 400–700 m altitude. The potential temperature across the inversion increased by ~ 8 K within a few hundred meters (a lapse rate of ~ 25 K/km). The relative humidity dropped dramatically from > 80% within MABL to ~ 20% above MABL. The capping inversion suppresses vertical mixing and prevents clouds from growing into deep convective systems. As a result, NB had almost clear sky whereas trade wind type cumulus clouds prevailed over CB, with substantial differences in aerosols and backscatter. Dust-laden continental air frequented NB, while CB appeared cleaner and lesser of continental influence (Fig. 1a). Analyses suggest that the inversion over NB is stronger due to advection of warm air from the Indian landmass over to NB by an anticyclonic circulation. Conversely, inversion over CB is maintained by the subsidence branch of Hadley Cell, while weakened by a southerly low-level jet-like flow.

Climatological (ERA5) analysis indicates that capping inversion is a recurring feature during the pre-monsoon regime and BOB attains its transition toward the monsoon with the dissolution of capping inversion (Fig. 1a), starting from late April; this is consistent with ASTraL observations. The evolution of capping inversion was studied via thermodynamic energy budget calculations (Holton 1992, Academic Press) for the atmospheric columns of NB and CB. When capping inversion dissipates and atmosphere shifts towards the transition regime, the total physics tendency (rate of change of variables) term of the budget dominates, indicating turbulent mixing/diabatic and unresolved processes. Additionally, the gradient Richardson number Rig (via rawinsondes) at the MABL top approached ~ 0.25-1 when atmosphere is shifting toward transition regime (Figure 1b-e).

The low-level jet (LLJ) over NB is strong, southwesterly, diurnally varying in magnitude and profile shape, and appears just above MABL near the inversion ~ 500–800 m. It's peak wind speed exceeds 10-12 m/s (Fig 2d), typically occurring at 04 local time (22 UTC). According to ERA5 analysis, LLJ in coastal regions may exceed 20 m/s. Daytime surface winds are generally weak, but accelerate after the sunset. Similar wind variability was observed by a mooring in NB during April-May 2015, suggesting persistent nature of LLJ. In the evening, the jet appeared narrow and sharply defined across the capping inversion, but became broader and more elevated overnight. Numerical

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experiments with a 1D model also show the evening strengthening of inversion due to warm continental air advection that isolate LLJ from underlying turbulence of MABL. This decoupling reduced frictional damping and helps sustenance of LLJ. In all, LLJ is a result of thermally induced pressure-gradients, Coriolis effects and frictional damping.

In a parallel study, both 2023 and 2024 campaign data were analyzed to elicit conflating influences of intraseasonal oscillations, Convective Coupled Kelvin Waves (CCKW) and MWP on monsoon onset (Fig. 3). The SSTs were anomalously warm in both basins during the monsoon transition. The SST and MWP were particularly pronounced in AS, exceeding 31degC. In both years, tropical cyclones developed in the onset phase. The 2023 cruise sampled the wake of Tropical Cyclone Biparjoy (TC23), while in 2024 the passage of a strengthening depression and subsequent wake of TC Remal (TC24) were observed. Despite elevated SST conditions, the two storms evolved quite differently: TC23 intensified substantially over AS, whereas TC24 was a faster-moving system that remained relatively weak until landfall in Bangladesh. In both years, the monsoon onset appeared to be influenced by preceding cyclones. These contrasting behaviors suggest factors other than SST are involved in TC initiation and intensification during monsoon onset. This is particularly important since MWP in the western Indian Ocean has expanded in extent and intensity in recent decades (Fig. 3).

Considering that tropical cyclones may be strongly modulated by intraseasonal oscillations and equatorial waves (e.g., Schreck et al., MWR, 3999, 2015), the nexus between [coherent] large-scale atmospheric disturbances and cyclogenesis was examined. Wave-filtered analyses of outgoing longwave radiation reveal both TC23 and TC24 were preceded by profound CCKW events originated over Africa, with amplification while traveling over the warm ocean (Phadtare & Fernando, GRL, 52, 2025); see Fig. 4. To this end, in a global survey, all CCKWs were tracked, and regions of amplification over AS and BOB were identified. A connection between pre-monsoon cyclone activity and CCKW propagation into cyclogenesis area was identified suggesting, at least in this single realization, CCKWs play an important role in thermodynamic preconditioning of atmosphere for deep convection and cyclogenesis (Fig. 4).

The NCAR PI continued to exercise a new coupled LES code that runs atmospheric and oceanic components with coupling routines linking simulations in the following order at each time step: (i) interpolate OBL currents and SST to the first model level in MABL; (ii) surface fluxes are then computed using MABL and OBL fields; and (iii) then the MABL surface fluxes are interpolated and communicated to the OBL. After these steps each LES is stepped forward using the same time step. The coupled code was used over a range of unstable stability, ranging from free convection to nearly neutral for an initially heterogeneous ocean surface. A 2D cold dense sub-mesoscale filament with horizontal x-width of 6 km that smoothly blends into the OBL over a depth of 60 m was imposed. The results show time dependent MABL-OBL coupling over meters to kilometers scales that varies with atmospheric stability. The free convection results are particularly interesting as they show a MABL cold pool extending over $-2 < x < 2$ km and the full depth of MABL ~ 500 m. The OBL filament induces clockwise and counterclockwise secondary circulations in the ABL u-field, due mainly to OBL temperature anomaly (Fig. 5). The free convection simulation also shows secondary circulation up to the MABL top, with a particularly interesting spatial growth of the moisture field at late times.

High-wind MABL above surface waves were simulated using a LES model that uses a non-orthogonal, time dependent, wave-fitted mesh. The three-dimensional wave surfaces h(x,y,t) built from spectral observations of SASCWATCH were used. The measured wind speeds varied over U10 = [15 - 35] m/s for wave age Cp/U10 ~1 with cutoff frequency 0.5 Hz (Cp is the phase speed). Large and small LES domains were used to examine the sensitivity of solutions to the airflow grid and wave resolutions. Flow visualization shows skimming over the wave troughs without intermittent flow separation characteristics of breaking-dominant waves, suggesting removal of intermittent breaking during the averaging of wave spectra. In the small domain LES, the average momentum flux computed along the wave following coordinates shows approximately a 25% contribution from the fluctuating pressure field correlated with the slope of the grid lines. Arguments were offered on how LES momentum fluxes can be interpreted in a “motion-averaged” framework similar to field observations. The surface drag computed from the LES subgrid roughness model and surface pressure flux agrees with wind-wave tank observations collected for strongly forced waves. In agreement with observations, LES shows a saturation Cd ~ 0.003 for winds > 25 m/s; Fig. 6.

Training Opportunities:

Two graduate students (Devmi Gamage and Selina Bolella) and a post-doctoral fellow (Jayesh Phadtare) participated in research. Selina Bollella is a NDSEG Fellow. During the campaign and thereafter, grad students were trained to operate instruments, conduct data processing, handle campaign logistics, while interacting with a host of collaborators from several national laboratories and participating universities.

Devmi Gamage was selected to participate in the LASER (Leadership Advancing Socially Engaged Research) program at UND from August 2025 – October 2026. It is an interdisciplinary professional development program focused on leadership development, research communication, mentoring and the social and ethical dimensions of

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research. The program consists of a yearlong seminar series including participant-led workshops. As a part of the program, a platform was developed to connect students and faculty engaged in fluid dynamics research across the College of Engineering at Notre Dame (https://graduateschool.nd.edu/graduate-training/leadership/laser/2025-laser-training-cohort/).
Devmi Gamage is also a participant of a weeklong College of Engineering writing retreat at Kylemore Abbey, Ireland, in October 2025. The retreat provided 35-40 hours of dedicated time for research and dissertation writing, along with opportunities for peer interaction and professional development. She also collaborates with Dr. Hemantha Wijesekera of the Naval Research Laboratory (Stennis), who is a participant of the ASTraL project.

Selina Bolella participated in a 10-week summer research internship through the Naval Research Enterprise Intern Program (NREIP) at the Naval Research Laboratory (NRL) in Monterey, California, from June 15 to August 21, 2026. She was jointly mentored by Drs. Sue Chen and Jonathan Christophersen, with whom the University of Notre Dame collaborated during the ASTraL 2025 field campaign. Her project, “Atmospheric Forcing, Ocean Subsurface Response, and Their Role in the Indian Summer Monsoon”, utilized observational data from ASTraL 2024 and 2025 field campaigns together with output from the Navy Coastal Ocean Model (NCOM) and Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS). Her research focused on quantifying the dominant processes controlling turbulent air-sea heat fluxes during the Indian Summer Monsoon transition and evaluating model representation of these interactions. The internship provided advanced training in observational and numerical model analysis while strengthening the ongoing research collaboration between the University of Notre Dame and NRL Monterey.

The post-doctoral fellow Jayesh Phadtare was mentored in research and professional development by the PI Fernando.

Results Dissemination:

Journal articles:
1. Johnson, L., Tandon, A., Lee, C., Sreenevas-Kumar, Mohapatra, M., Rao, S., Chen, S., Fernando, H.J.S. and Goes, J., 2025: Air-Sea Transition Layers during the Indian Summer Monsoon, Bulletin of the American Meteorological Society, E2509–E2518, Published 17 Dec (Print 01 Dec), https://doi.org/10.1175/BAMS-D-24-0239.1
2. Wijesekera, H.W., Teague, W.J., Hallock, Z.R., Wang, D.W., Luecke, C., Jarosz, E., Jensen, T., Fernando, H.J.S., and Jinadasa, S.U.P., 2026: Near-inertial wave observations in the Bay of Bengal, Deep Sea Research, 229, Article: 104686, https://doi.org/10.1016/j.dsr.2026.104686.
3. Phadtare, J., Thompson, E., Fernando, H.J.S., 2025: Dynamics of capping inversion and low-level jet over the Bay of Bengal in premonsoon season. Journal of the Atmospheric Sciences, ID: JAS-D-26-0086 (In Revision)
4. Port, J., F. Addona, T. Hara, F. Veron, & P. P. Sullivan, 2026: Effect of surface wave shoaling on air-sea momentum exchange, submitted, Journal of Geophysical Research - Oceans.
5. Kukulka, T. & P. P. Sullivan, 2026: Interactions of Langmuir turbulence with wind and tide-driven currents in a depth-varying coastal channel. submitted, Journal of Physical Oceanography.
6. Jiang, W., P. P. Sullivan, & T. W. N. Haine, 2026: Energetics of submesoscale frontogenesis and arrest in an upper-ocean dense filament, submitted, Journal of Fluid Mechanics.
7. Patton, E. G., J. J. Finnigan, I. N. Harmen, & P. P. Sullivan, 2026: Turbulent flow over isolated forested hills of varying shape and steepness. Journal of Fluid Mechanics, 1026, A16-1-A16-39.
8. Sullivan, P. P., J. C. McWilliams, & E. G. Patton, 2025: An investigation of coupled atmospheric and oceanic boundary layers using large eddy simulation. Journal of the Atmospheric Sciences, 82, 829-846.
9. Huusko, L., T. Mukha, L. L. Donati, P. P. Sullivan, P. Schlatter, & G. Svensson, 2025: Large eddy simulation of canonical atmospheric boundary layer flows with the spectral element method in Nek5000. Journal of Advances in Modeling Earth Systems, 17, 1-29.

Conference Presentations:

1. Bolella, S., Gamage, D., Phadtare, J., and Fernando, H.J.S. 2026: Impact of Tropical Cyclone Formation on Summer Monsoon Onset. American Geophysical Union, Ocean Sciences Meeting (No. 888, pp. CC24B-0888).
2. Gamage, D., Bolella, S., Modjeski, G., Phadtare, J. and Fernando, H.J.S. 2026: The Role of Rossby-Wave Induced Subsidence in Developing Layered Mid-Tropospheric Dry Intrusion Over the Arabian-Sea: Observations and Diagnostics. Oceans Sciences Meeting, Glasgow, 23-27 February 2026 (Poster Presentation).
3. Chen, S., Jacob Yung, Paul Ciesielski, Po-Hsiung Lin, Jonathan Christophersen, Christerphor Sepka, Harindra Fernando, 2006: Rawinsonde Observations of Maritime Continent and Indian Ocean Summer Monsoons, 37th Conference on Hurricane and Tropical Meteorology, 30 March-03 April 2026, San Diego, CA.
4. Fernando, H.J.S., Marine Atmospheric Boundary Layer: Some Recent Developments. Presented at the: Marine Atmospheric Research on Boundary Layers over East China/Yellow Seas (MARBLES), ONR-G Workshop, Oakwood Premier COEX Center, Seoul, Republic of Korea, June 25-26, 2025. [Invited]
5. Fernando, H.J.S., 2005: From Fatima to Marbles. Presented at the: Marine Atmospheric Research on Boundary Layers over East China/Yellow Seas (MARBLES), ONR-G Workshop, Oakwood Premier COEX Center, Seoul, Republic of Korea, June 25-26.
6. Bolella, S., Gamage, D., Phadtare, J. and Fernando, H.J.S., 2026: Interactions of Warm Pool & Convectively

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Coupled Kelvin Waves, Presented at the ONR EKAMSAT/ASTraL review, Washington DC, May 12-13.
7. Phadtare, J., Thompson, E., and Fernando, H.J.S., 2026: Transition in the atmospheric boundary layer over the Bay of Bengal during monsoon onset, Presented at the ONR EKAMSAT/ASTraL review, Washington DC, May 12-13.
8. Gamage, D., Bolella, S., Phadtare, J., and Fernando, H.J.S., 2026: Pre-monsoon low level capping inversion over the Bay of Bengal, Presented at the ONR EKAMSAT/ASTraL review, Washington DC, May 12-13.
9. Chen, Sue, Fernando, HJS., Phadtare, J., Yung, J., Ciesieslski, P., Ling, P-H., Christopherson, J., and Sepka, C., 2026: Radiosonde Observations of Maritime Continent and Indian Ocean Summer Monsoons, Presented at the ONR EKAMSAT/ASTraL review, Washington DC, May 12-13.
10. Gamage, D., Bolella, S., and Fernando, H.J.S., 2027: Recurring thermodynamic layered structure in the Arabian Sea Marine Boundary Layer during Indian Summer Mon soon onset. 11th International Symposium on Environmental Hydraulics. Iowa City, IA, 1-3 June 2027 - accepted
11. P.P. Sullivan, 2026: High wind atmospheric boundary layers over large resolved waves: LES results. Air-Sea Interaction: A Symposium in Honor of Isaac Ginis and Tetsu Hara, Providence, RI, June 11-12 [invited].
12. P.P. Sullivan, 2026: High wind atmospheric boundary layers over large resolved waves: LES results. ONR PI meeting ASTral, Washington, DC, May 12-13.
13. P.P. Sullivan, 2-25: Investigations of (un)coupled atmospheric and oceanic boundary layers: LES results, AMS Annual Meeting, New Orleans, LA, Jan 12-16 [invited].
14. P.P. Sullivan, 2025: Coupled atmospheric and oceanic boundary layers: LES results. 25th Symposium on Boundary Layers & Turbulence, Torino, Italy [invited].
15. P.P. Sullivan, A comparison of subfilter-scale motions from fine mesh LES and observations of stable atmospheric boundary layers, 2025: 25th Symposium on Boundary Layers & Turbulence, Torino, Italy.
16. P. Sullivan, 2026: Large eddy simulations of high wind atmospheric boundary layers above a spectrum of measured waves. University of Notre Dame Environmental Fluid Dynamics Seminar, South Bend, IN, Sept. 22 [invited].
17. Sullivan, P.P., Richter, D.H., Fernando, H.J.S., and McWilliams, J., 2026: High Wind Atmospheric Boundary Layer over Large Resolved Waves, Presented at the ONR EKAMSAT/ASTraL review, Washington DC, May 12-13.

Plans Next Period:

The following are the project-team plans for the next reporting period:

Devmi Gamage: ASTraL 2023 Manuscript submission, November 2026; ASTRAL 2024 Data analysis, August-December 2026; ASTraL 2024 Manuscript writing, December-January 2026; ASTraL 2024 Manuscript submission, March 2027; Thesis dissertation writing: January-April, 2027; ASTraL 2025 field campaign data analysis, summer 2027 and submission of a manuscript after graduation; and, Thesis defense: June-July 2027

Selina Bolella will work toward completing her Ph.D. candidacy examination during the upcoming spring semester and completing her first manuscript, titled “Warm Pool and Convectively Coupled Kelvin Wave Interactions during Monsoon Onset”. She will work on her PhD research project, a continuation from her NREIP internship with Drs. Sue Chen and Jonathan Christophersen, titled “Atmospheric Forcing, Ocean Subsurface Response, and Their Role in the Indian Summer Monsoon.” She plans to return to NREIP in summer 2027 to continue this research.

Jayesh Phadtare: Complete the manuscripts on cold pool observations from ASTraL-EKAMSAT 2024 (Leg-2) cruise; Study biases in coupled model simulation (performed by Aneesh Subramanian’s group at University of Colorado, Boulder) due to inadequate representation of cold pools; Investigate the climatology of capping inversion and LLJ over the region with a reanalysis dataset; and, Update the Doppler Lidar wind dataset by including signal-to-noise ratio, backscatter, and vertical velocities.

Peter Sullivan: Continue using the coupled atmosphere-ocean LES code for process studies emphasizing the role of submesoscale turbulence in ABL-OBL coupling; Investigate MABL response in the presence of measured wave fields; and, Submit a manuscript describing the results.

Honors and Awards:

Co-PI Peter P. Sullivan was chosen by the American Meteorological Society for The Award For Outstanding Contributions to Boundary-Layer Meteorology, for his pioneering work on developing highly reliable large eddy simulations for innovative applications to the atmospheric and oceanic boundary layers and air-sea interactions

PI Fernando received the Springer-Nature Publishing Editor of Distinction Award 2025

PI Fernando delivered the Invited Keynote Address at the Sixteenth (16) International Conference on Hydrodynamics, April 14-18, Macau Institute of Technology 2026 – an International Association of Hydro-environment Engineering and Research (IAHR) Conference.

PI Fernando delivered an Invited Keynote Lecture on Fog and Ice Fog at the Seventy Eighth (78) American Physical

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Society, Fluid Dynamics Meeting, Houston, TX, November 23-25, 2025.

Technology Transfer:

Nothing to Report

Participants:

- Harindra Fernando (PD/PI) - 1 month(s)
- Peter Sullivan (Co PD/PI) - 1 month(s)
- Jay Hyde (Technician) - 1 month(s)
- Scott Coppersmith (Other Professional) - 3 month(s)
- Jayesh Phadtare (Postdoctoral (scholar, fellow or other postdoctoral position)) - 12 month(s)
- Devmi Gamage (Graduate Student (research assistant)) - 12 month(s)
- Selina Bolella (Graduate Student (research assistant)) - 12 month(s)

Partners:

No partners found.

Other Collaborators:

The UND Group closely collaborated with other ASTral participants, especially, NRL (Stennis and Monterey), Oregon State University, University of Colorado, University of Massachusetts, Ocean University of Sri Lanka (Colombo) and Indian Institute of Tropical Meteorology (Pune) .

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Figure Files:

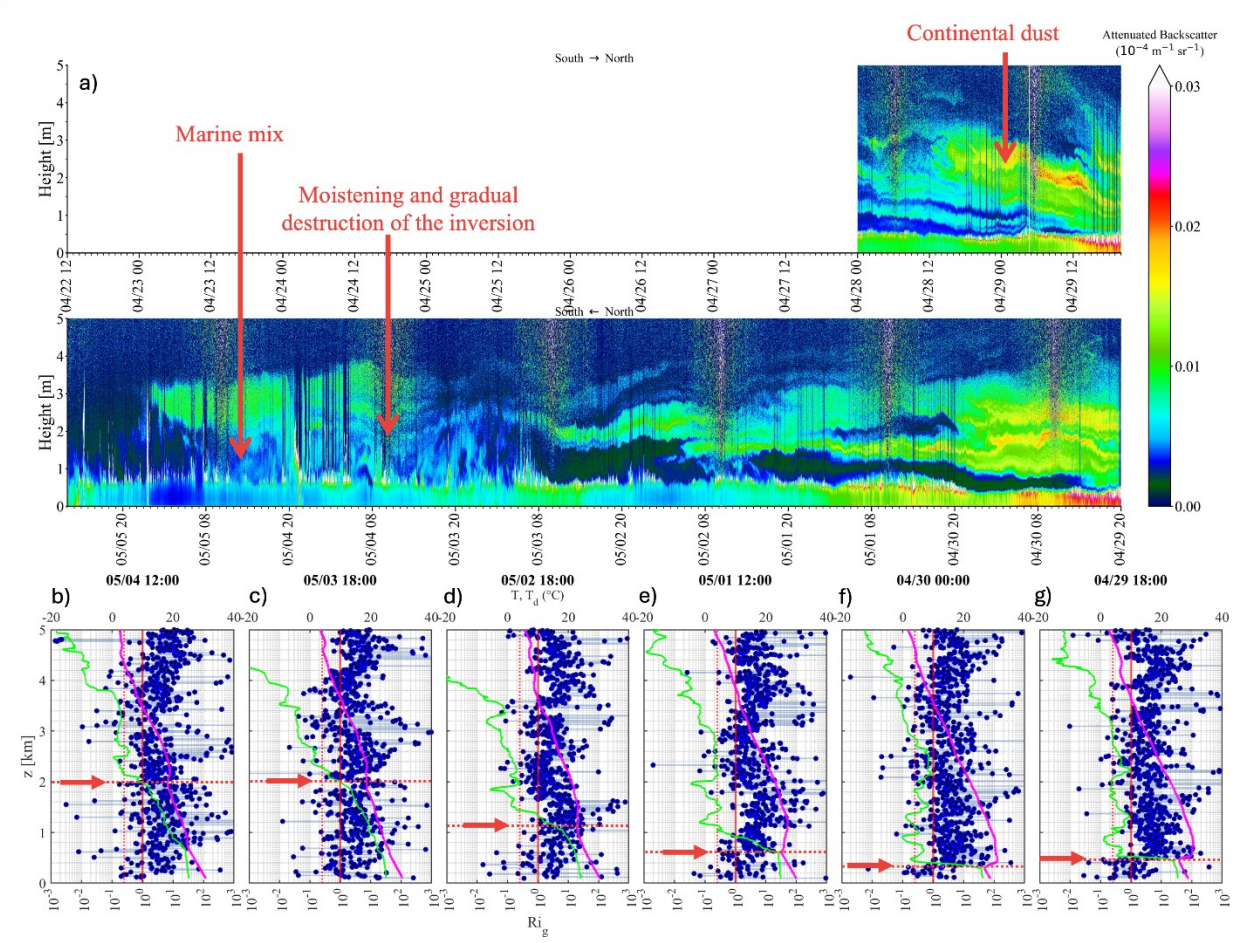


Figure 1: (a) CL 61 attenuated backscatter profiles along South-to-North (top) and North-to-South (bottom) transects in the BOB. (b-g) are Ri_g profiles calculated from rawinsonde observations along North-to-South transect (g) shows the Ri_g profile during the strong capping inversion while (b) shows the Ri_g profile during the weakening of the capping inversion. The red solid and dashed lines indicate Ri_g = 1 and Ri_g = 0.25 respectively. Ri_g was calculated with a vertical resolution of 5m. Horizontal red arrows show the estimated height of the capping inversion. The temperature and dew point are shown in purple and green color, respectively.

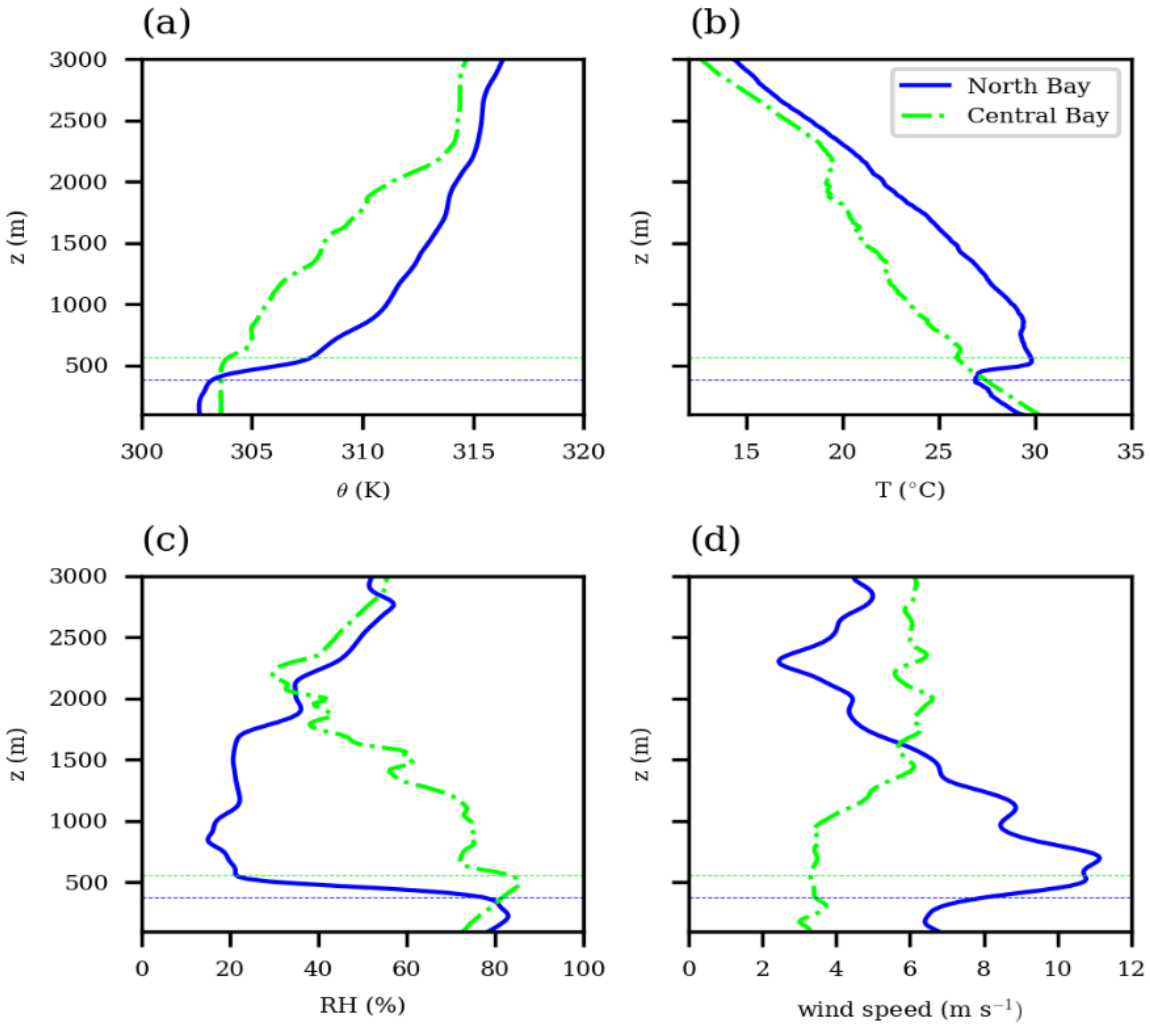


Figure 2: Vertical profiles of (a) potential temperature (θ), (b) dry bulb temperature, (c) relative humidity RH, and (d) wind speed over the North Bay (89.37◦E, 17.54◦N at 000 UTC 30 April) and Central Bay (87.07◦E, 10.79◦N 000 UTC 05 May). Thin dashed lines show the mixed-layer height in the respective soundings.

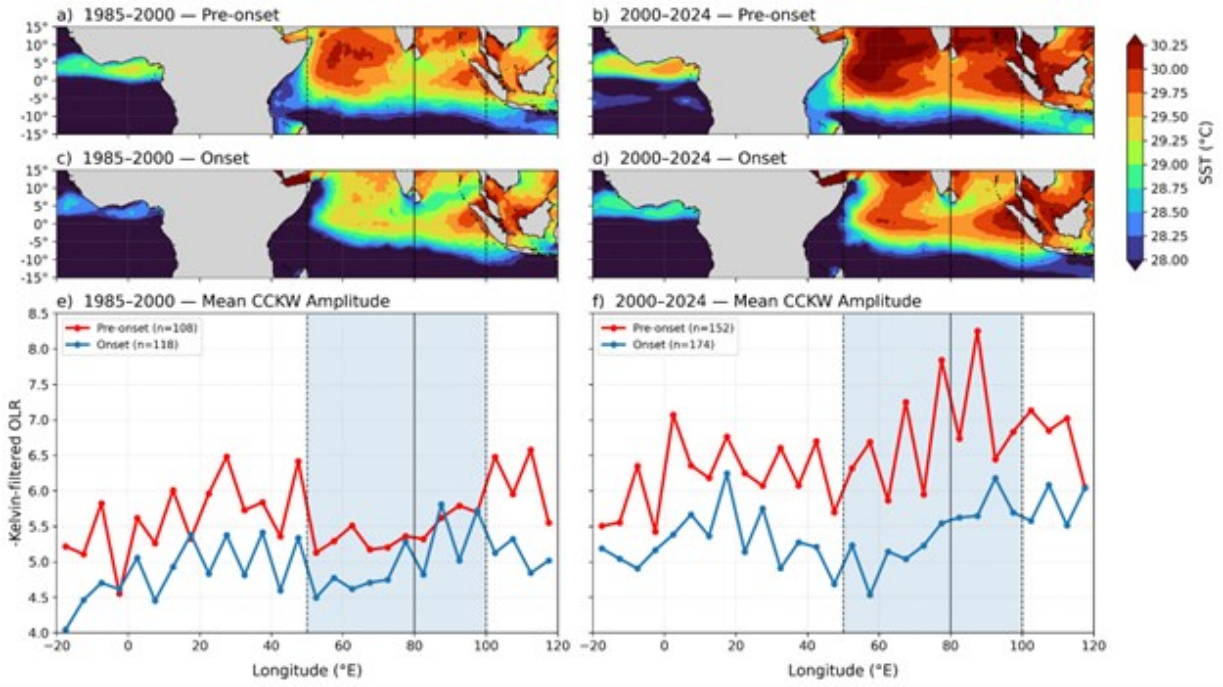
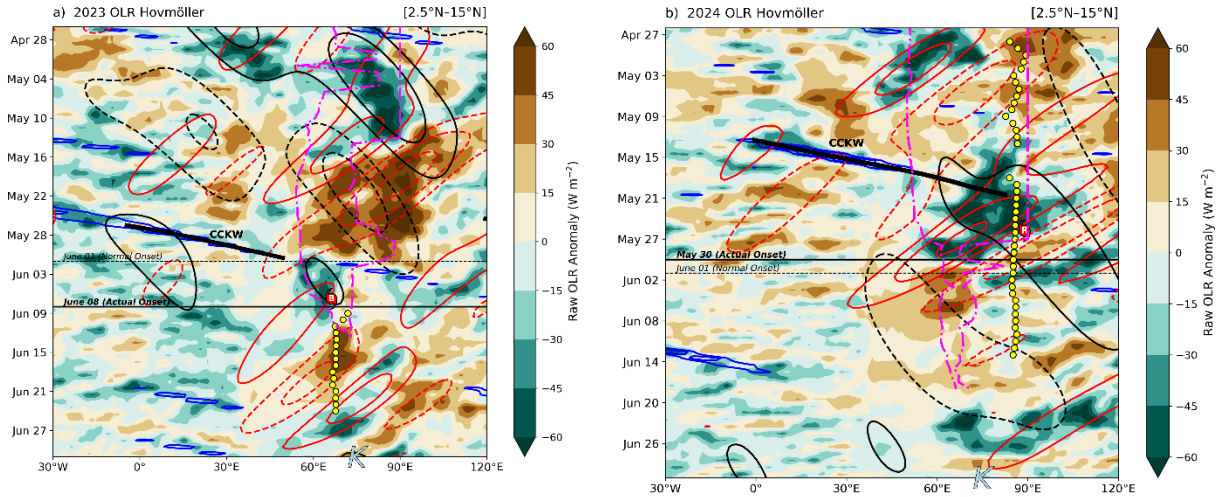


Figure 3: Mean sea surface temperature (SST); °C) during pre-onset (1–20 May; top row) and onset (21 May–13 June; middle row) periods: (a,c) 1985–2000 and (b,d) 2000–2024. (e-f) shows corresponding mean convective amplitude of Kelvin wave-filtered OLR averaged over 15°S–15°N. Blue boxes denote the Arabian Sea (50°–80°E) and Bay of Bengal (80°–100°E) regions. Red curves are pre-onset Convectively Coupled Kelvin Wave (CCKW) amplitudes, while blue curves represent onset-period amplitudes. Note the escalation of pre and monsoon-onset CCKW waves during the 2000-2024 period.



(a) (b)

Figure 4: Hovmöller diagram of OLR anomalies for (a) 2023 and (b) 2024. Filtered Kelvin waves (blue), MJO (black), and equatorial Rossby waves (red) are shown. Negative anomalies are solid contours and positive anomalies are dashed contours (5 W m^{-2} intervals). Storm symbols - cyclogenesis; black line - tracked CCKW of interest; yellow markers - daily ship longitude along the cruise track. CCKW tracking algorithm was developed using Kelvin-filtered OLR anomalies of enhanced convection. Tracks were filtered to retain coherent events, and their duration, propagation distance. Convective intensity based on a −1σ intensity threshold and local minima were calculated. The normal and actual monsoon onset dates for each year and the general location of Kerala (blue "K" ~75.5ºE on the longitude axis) are marked. The magenta dashed line is the evolution of warm pool's ≥ 30.5°C longitudinal extent.

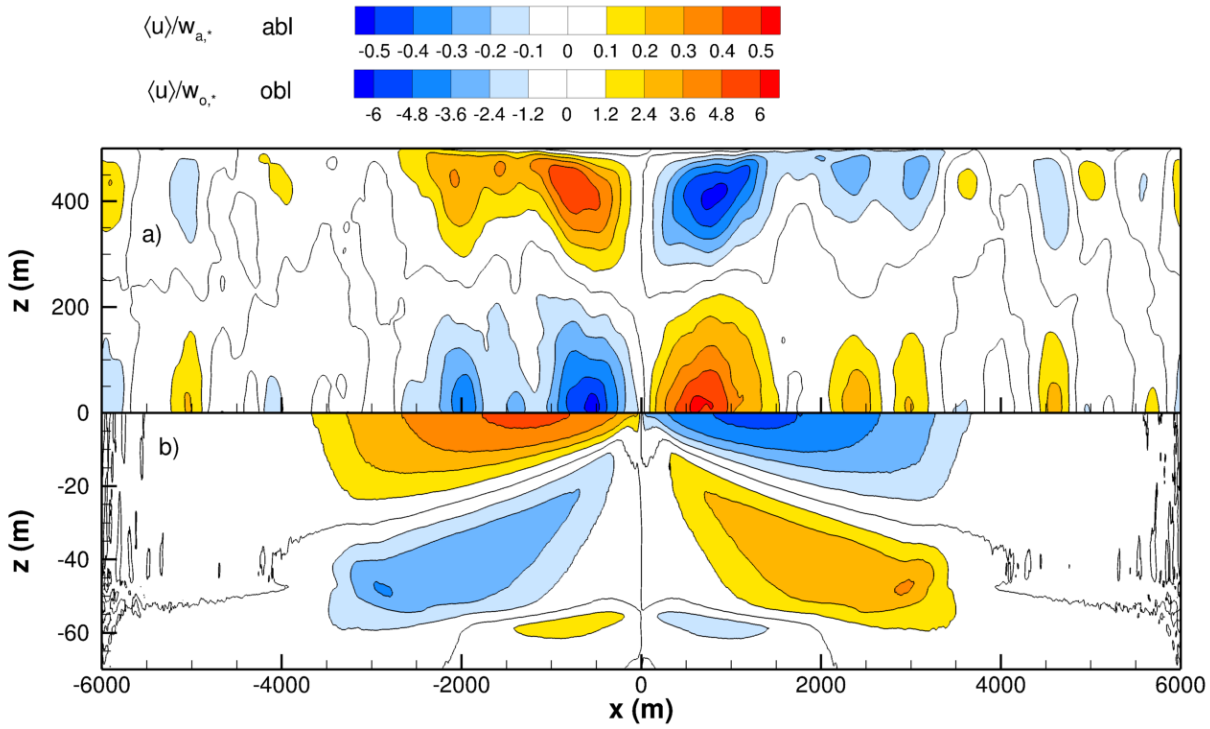


Figure 5: Average streamwise velocity $<u_a>/w_{a,*}$ in the MABL (upper panel) and $<u_w>/w_{o,*}$ in the OBL (lower panel) at the time of maximum frontogenesis of a cold dense filament time = 11.4 hr. Here the free convective velocity scales in the ABL and OBL are w_{a*} and w_{o*}, respectively. The MABL and OBL velocity fields are averaged in y. Under free convective conditions the OBL filament that undergoes frontogenesis leaves an average signature in the MABL through the filament's temperature field. Near the water surface the opposing left and right branches of the secondary circulation are opposite in sign compared to the ABL circulation, (i.e., negative, positive) winds. This MABL response is mainly due to temperature anomaly in the OBL.

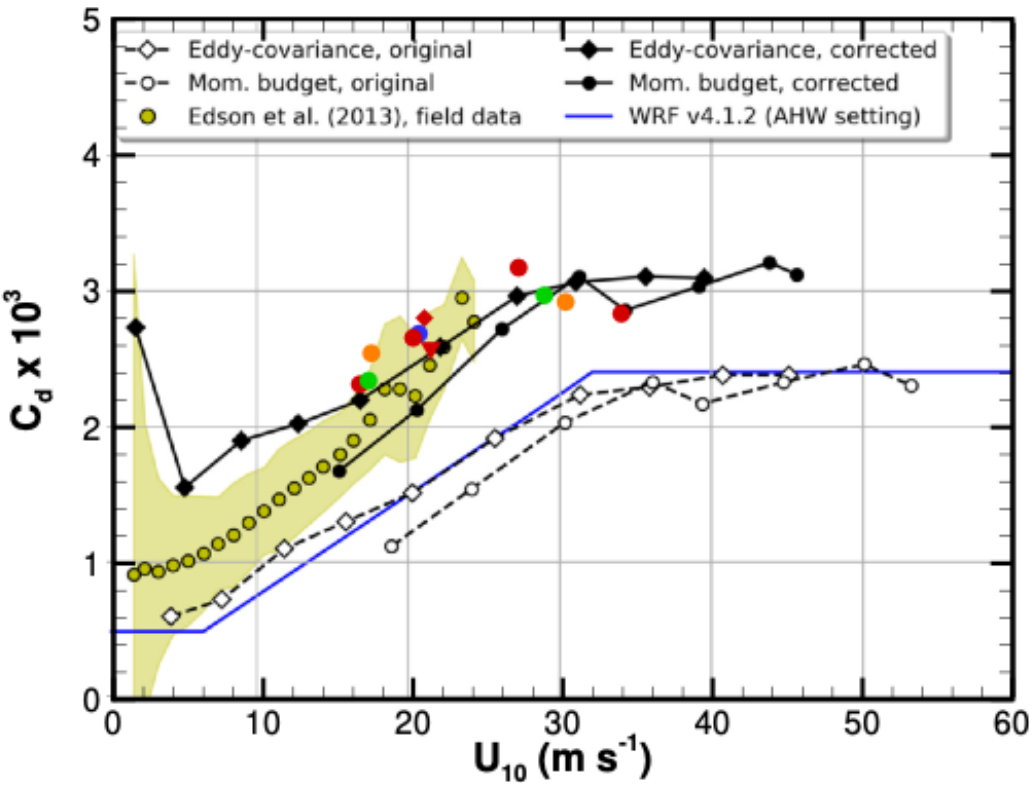


Figure 6: Comparison of drag coefficient C_d versus the 10-m wind speed U_{10}; figure adapted from Curic & Haus (2020, *GRL*). The LES estimates of C_d are the solid (red, green) bullets using meshes (512^3, 1024^2x512), respectively. The red (diamond, gradient, bullet) are cases with the SGS roughness z_o = (1, 1.5, 2) mm, respectively. The blue bullet is a simulation with swell and wind waves, and the solid brown bullets are from surface layer LES with zero Coriolis and no stratification. Observed wave spectrum is used as the surface boundary condition.